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SPATIAL DIVERSITY OF ECOLOGICAL STABILITY IN DIFFERENT TYPES OF SPATIAL UNITS: CASE STUDY OF POLAND

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Spring landscape of Roztocze, Poland.

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Spatial diversity of ecological stability in different types of spatial units: Case study of Poland

ABSTRACT: The study estimates and compares the spatial distribution of ecological stability within administrative units in Poland. Its method permitted the value of the coefficient of ecological importance parameter to be determined, and enabled the design of a spatial unit typology. The units originally analyzed were municipalities (Pol. *gminy*). In this variant, areas with low and average ecological stability were evidently dominant. Verifying the results obtained involved extending the study, and using of a square with sides of 1 km as the basic unit of assessment. This approach yielded dominance of areas extreme in terms of ecological stability. The spatial analyses also allowed for the spatial dependence of the phenomenon to be identified and illustrated spatially.

KEYWORDS: Coefficient of Ecological Importance, spatial autocorrelation, spatial planning, land cover, landscape, Poland

Prostorska raznolikost ekološkega ravnovesja v različnih tipih prostorskih enot: primer Poljske

POVZETEK: V raziskavi avtorici proučujeta in primerjata prostorsko porazdelitev ekološkega ravnovesja v upravnih enotah na Poljskem. Z izbrano metodologijo sta določili vrednost koeficienta ekološkega pomena in izdelali tipologijo prostorskih enot. Osnovna prostorska enota, ki sta jo najprej analizirali, je bila občina (pol. *gminy*). Rezultati so razkrili, da v njih prevladujejo območja z nizkim in povprečnim ekološkim ravnovesjem. Da bi avtorici preverili dobljene rezultate, sta raziskavo razširili in za osnovno enoto tokrat uporabili kvadrat s stranico 1 km, za katero so rezultati pokazali prevlado območij z ekstremnimi vrednostmi ekološkega ravnovesja. S prostorskimi analizami sta avtorici lahko določili tudi prostorsko odvisnost proučevanega pojava in jo prikazali v prostoru.

KLJUČNE BESEDE: koeficient ekološkega pomena, prostorska avtokorelacija, prostorsko načrtovanje, pokrovnost tal, pokrajina, Poljska

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1 Introduction

The cultural landscape is constantly evolving to meet the ever-changing needs of present and future generations. One of the main factors currently influencing significant changes in the landscape structure is human activity (Verburg et al. 1999; Verburg et al. 2002; Dotterweich 2008; Geri et al. 2010; Baran-Zgłobicka and Zgłobicki 2012; Ribeiro and Šmid Hribar 2019). New anthropogenic elements introduced into the natural environment contribute to landscape transformation. Their intensity has an impact on the ecological stability of the landscape. Considerable accumulation of such elements may lead to gradual degradation of the natural environment and disturbances in the area's ecological stability (Richling and Solon 1994; Król and Gałaś 2008).

Ecological stability is defined as the ecosystem's ability to return to equilibrium, or to its »normal« direction of development, via its own internal mechanisms. The sooner the ecosystem returns to its original balance, the more stable it is (Holling 1973; Vološčuk and Míchal 1991). Forman and Godron (1986) define landscape stability as the landscape's resistance to disturbances and its ability to regenerate after they occur. Bičik et al. (2015, 9) define it as »a condition that is inversely related to the amount of energy, material, and labor invested by the society so that the landscape remains in a balanced condition.« Over time, landscapes and ecosystems undergo natural transformations (Widacki 1979). As a result, the forms, functions, and significance of landscapes also change (Urbanc et al. 2004). Therefore, the stability of the natural environment is dynamic. Considering all of this, when a disruptive factor is introduced, the natural environment is not able to return to its exact original state, even though it can achieve an approximation of it (Balon 2006). Zaušková and Midriak (2007) also point to the dynamic ability of ecosystems to maintain and restore the conditions of their existence through self-regulatory mechanisms. This is reflected in their stability and resistance to natural and anthropogenic factors.

Two main trends are designated in landscape stability research (Balon 2006; Gigon and Grimm 2014). The first refers to natural areas capable of functioning owing to internal mechanisms, without human intervention: the »natural« approach (e.g., Gigon 1983; Geng et al. 2019). The second refers to stability assuming the presence of anthropogenic activities and economic uses of the natural environment: the »utilitarian« approach (e.g., Messerli 1983; Winiger 1983; Fuentes 1984; Zhang et al. 2017). a mixed approach also exists that combines both of these (e.g., Kienholz et al. 1984; Ganjurjav et al. 2019).

Pinpointing and evaluating the ecological stability of a landscape is a complex process, in which the level of ecological stability of a given area may reflect a coefficient of ecological importance. It can be expressed numerically, whereas the result is only an approximation of the reality behind the model (Bastian and Schreiber 1999). Mandatory large-scale landscape studies of this type have been conducted in the Czech Republic and Slovakia as part of their Territorial Systems of Ecological Stability (Moyzeová and Kenderessy 2015; Kočická et al. 2018). Meanwhile, a number of approaches to measuring ecological stability have been developed over the years, presented in works by Turner et al. (1993), Yang et al. (2016), and (Kazakov 2019), and others. Poland's attempts to estimate ecological stability levels to date have concerned the local level (the area of a municipality and the area around a water reservoir), as in Król and Gałaś (2008), Gałaś and Gałaś (2009), the regional level (Subcarpathia Province and Holy Cross Province) by Salata et al. (2016), Ciupa and Suligowski (2018), and the country level (based on land-use structure data from the Central Statistical Office for each province) by Harasim (2015). These studies appear insufficient, and do not provide necessary information on the ecological stability of Poland overall. The studies cited here primarily focus on selected areas of Poland, with analysis of various types of single spatial units, such as drainage basins, municipalities, or provinces. As a result, the results obtained are not comparable. Moreover, the local character of the research does not permit conclusions to be drawn regarding the level of ecological stability throughout the entire country. Some of them are also based only on statistical data or individually vectorized objects from base maps. Particularly in the second case, this carries the risk of generalization and subjectivity. It should be emphasized that the statistical data used in Harasim's work (2015) refer to the provincial level, and provide only a very general view of ecological stability, with no differentiation between them. The methodology adopted in this paper is the first attempt at comprehensive research on ecological stability carried out at the level of Poland's administrative units based on spatial data. This paper is an important contribution to help fill this research gap, and such an in-depth analysis of ecological stability is likely to be a useful tool for shaping the broadly defined spatial policy.

The objective of this study is to compare the spatial diversity of Polish municipalities' ecological stability and to calculate the spatial autocorrelation of this phenomenon in order to determine spatial dependencies. An additional aim is to verify the results by comparing them with those of an artificial geometric division; that is, a square with sides of 1 km.

2 Material and methods

The source material for this paper was the CORINE Land Cover (CLC) 2018 database maintained by the European Environment Agency. This database contains data on current land cover across all of European territory. The data contained in the database are hierarchically grouped at three levels. The first level consists of five main land-cover classes: anthropogenic land, agricultural land, forests and semi-natural ecosystems, wetlands, and water areas. The second and third levels provide further details within more precise categories (Heymann et al. 1994). Poland's data were provided by the Chief Inspectorate of Environmental Protection.

In our study, estimating the degree of ecological stability in administrative units employed the Bičik's (1995) method of classifying and verifying areas. For the purpose of this analysis, the typology of land-cover classes included in CLC 2018 (Table 1) was replicated to enable appropriate weights of ecological importance (*cei*), as proposed by Bičik et al. (2015), to be assigned to particular classes of land cover. This treatment allowed a classification to be obtained that can be used in similar area studies at the local, regional, national, and international scale. An additional advantage of the division proposed in this paper is the fact that the CLC database is widely available, free of charge, and identical for many European countries. It offers access to unified data, reinforcing the spatial compatibility of the dataset, and permitting comparison of different areas.

A number of methods exist for determining a site's level of ecological stability. The majority are based on assigning a numerical value to the ecological stability indicator, allowing for a qualitative assessment of the area under investigation. The most basic methods are those proposed by Míchal (1982), Löw (1984), and Miklós (1986). Míchal's method is the simplest. It pertains to the relationship between the surface area of areas defined as stable (e.g., forests, waters, meadows, and pastures) and the surface area of unstable areas (e.g., arable and built-up land). This approach was modified by Löw to assign individual landscape elements to five degrees of stability that were given constants reflecting their importance. The process developed by Miklós does not divide landscape elements into stable and unstable ones, but introduces numerical coefficients that differentiate their ecological stability. This method reflects the ecological stability of the spatial composition of the area studied by determining the relation between the sum of products of areas occupied by individual landscape elements and their corresponding weights of ecological stability to the total area of the terrain in question. This approach was the starting point for Bičik et al. (2015) in their procedure for assessing complex ecological stability used in this paper. In line with the adopted methodology (Bičik et al. 2015), the Coefficient of Ecological Importance (CEI) was used to estimate the degree of ecological stability. It is the sum of the products of the appropriate weights of ecological stability and the percentage of the area of each basic unit of assessment (BUA) that is covered by the classes of the features mentioned above. Graphically, it represents a projection of the degree of ecological stability of these BUAs. The CEI for an individual spatial unit is expressed as the following formula (Bičik et al., 2015):

$$CEI_i = \sum_{(c=1)}^{n} cei_c \cdot P_{ci} \tag{1}$$

where: CEI_i = coefficient of ecological importance in BUA_i, cei_c = weight of ecological importance of land-cover class c, P_{ci} = percentage of the area of the BUA_i covered by land-cover class c, n = number of land-cover classes, and i = individual BUA.

The values of individual weights of ecological importance (*cei*) reflect the ecological stability of individual landscape elements, and fall within a range of 0 to 1, where the value »0« represents anthropogenic areas (heavily transformed by human activity), and »1« represents valuable natural areas (scarcely transformed by human activity). Similarly, values of the synthetic coefficient of ecological importance (CEI) are in a range from 0 to 1, with the value »0« standing for ecologically insignificant areas, and »1« ecologically significant areas. The level of ecological stability of a study area increased with an increase in the

Table 1: Reclassification of CORINE Land Cover 2018 land-cover classes with assigned *cei* weights.

Land-cover class	Level I CLC	Level II CLC	Level III CLC	CLC Code	*cei* weight
1. Forest and semi-natural areas	Forest and semi-natural areas	Forest	Broad-leaved forest	311	1.00
			Coniferous forest	312	
			Mixed forest	313	
		Scrub and/or herbaceous vegetation associations	Natural grassland	321	
			Moors and heathland	322	
			Sclerophyllous vegetation*	323	
			Transitional woodland/shrub	324	
		Open spaces with little or no vegetation	Beaches, dunes, sands	331	
			Bare rock	332	
			Sparsely vegetated areas	333	
			Burnt areas	334	
			Glaciers and perpetual snow*	335	
2. Wetlands and water areas	Wetlands	Inland wetlands	Inland marshes	411	0.79
			Peat bogs	412	
		Coastal wetlands*	Salt marshes*	421	
			Salines*	422	
			Intertidal flats*	423	
	Water bodies	Inland waters	Water courses	511	
			Water bodies	512	
		Marine waters	Coastal lagoons	521	
			Estuaries*	522	
			Sea and ocean	523	
3. Permanent grasslands	Agricultural areas	Pastures	Pastures	231	0.64
4. Permanent crops	Agricultural areas	Permanent crops	Vineyards*	221	0.34
			Fruit trees and berry plantations	222	
			Olive groves*	223	
5. Other agricultural areas	Agricultural areas	Arable land	Non-irrigated arable land	211	0.14
			Permanently irrigated land*	212	
			Rice fields*	213	
		Heterogeneous agricultural areas	Annual crops associated with permanent crops*	241	
			Complex cultivation patterns	242	
			Land principally occupied by agriculture, with significant areas of natural vegetation	243	
			Agro-forestry areas*	244	
6. Other areas	Artificial surfaces	Mine, dump and construction sites	Mineral extraction sites	131	0.14
			Dump sites	132	
			Construction sites	133	
		Artificial, non-agricultural vegetated areas	Green urban areas	141	
			Sport and leisure facilities	142	
7. Built-up areas	Artificial surfaces	Urban fabric	Continuous urban fabric	111	0.00
			Discontinuous urban fabric	112	
		Industrial, commercial and transport units	Industrial or commercial units	121	
			Road and rail networks and associated land	122	
			Port areas	123	
			Airports	124	

* Classes that do not occur in Poland. They are included in the table to ensure comparability with other potential studies in other EU countries.

index value. It is worth emphasizing that within the same methodology involved in the approach – the concept of planning used to optimize spatial organization, protection, and utilization of the landscape, called Landscape Ecological Planning (LANDEP; Miklós et al. 2019) – some authors use different ranges for the degree of ecological stability values (e.g., Reháčková and Pauditšová 2007; Igondova et al. 2016; Miklós and Špinerová 2019).

Two variants were used to estimate the degree of ecological stability. The first one used *gminy* – administrative units that roughly correspond to municipalities – as the basic unit of assessment. The average area of a municipality was 126 km². The main advantage of using this type of unit is that the message of the results is clear, and data for comparisons are commonly available from various offices and agencies. Unfortunately, a very serious disadvantage of accepting administrative units as BUAs is their internal heterogeneity that does not fully reflect the spatial distribution of the phenomenon surveyed. The heterogeneity of the area makes it difficult to compare individual units' results (Balon and Krąż 2013). In order to verify and improve the precision and level of detail of the results in this paper, a second variant was used, based on an artificial geometric division of the area studied, wherein a square with sides of 1 km was adopted as the BUA. The consistency in the area of each field – in this case 1 km² – facilitates statistical calculations, making individual results easily comparable with one another. Moreover, a BUA with a smaller area presents differences in the spatial distribution of ecological stability better and more precisely.

Regardless of the variant adopted, the procedure for estimating ecological stability was conducted in the same way. CLC 2018 land-cover classes were trimmed to the borders of the BUA. Then, each newly created parcel within a given BUA was assigned an appropriate weight (*cei*, according to land-cover class), and its share in the total area of the BUA (*P*) was calculated. Based on the above, the municipalities were ordered based on the numerical value of their ecological stability coefficient. The calculated values permitted spatial units to be classified into five equal classes corresponding to different degrees of ecological stability. Because the method used in this paper does not have fixed threshold values for individual classes, the classification proposed by Petrovič (2005) and used in works such as Mederly et al. (2006), Boltiziar and Olah (2009), Salata et al. (2016), and Krivosudský (2012) was applied. The following classes were distinguished: A: very low ecological stability (CEI 0.00–0.20); B: low ecological stability (CEI 0.20–0.40); C: average ecological stability (CEI 0.40–0.60); D: high ecological stability (CEI 0.60–0.80); E: very high ecological stability (CEI 0.80–1.00).

Determination the spatial dependence of the phenomenon studied involved performing an analysis of spatial autocorrelation. Spatial autocorrelation permits estimation of the relationship between the value of the examined variable in a given location and the value of this variable in another location. Spatial autocorrelation is referred to when a given phenomenon occurring in a particular location increases or decreases the probability of its occurrence in the neighborhood (Bivand 1980). This paper employs the global Moran's I index, one of the best-known autocorrelation coefficients. It is expressed by the following formula (Moran 1950):

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2} \tag{2}$$

where: z_i = deviation of an attribute for feature (BUA) i from its mean ($x_i - \hat{X}$), z_j = deviation of an attribute for feature j from its mean ($x_j - \hat{X}$), $w_{i,j}$ = spatial weight between feature i and j, n = total number of features, S_0 = aggregate of spatial weights.

The Global Moran's I index permits detection of the strength and character of spatial dependence in the area studied. The statistical value is in a range from −1 to 1, where negative values indicate occurrence of different values of observations in the neighborhood, 0 indicates randomness of the distribution of observation values (lack of autocorrelation), and positive values indicate similarity of values located in the neighborhood (Janc 2006).

Moreover, the Local Indicator of Spatial Association (LISA) is used to identify systems occurring in space. It allows for estimation of the degree of similarity of individuals to their neighbors, and determination of the statistical significance of these relationships (Anselin 1995). As a result, each spatial unit was classified as a high-value unit with neighbors of similar value (High-High Cluster), a low-value unit with neighbors of similar value (Low-Low Cluster), a high-value unit with low-value neighbors (High-Low Outlier), a low-value unit with high-value neighbors (Low-High Outlier), or a unit without significant statistical local autocorrelation (Janc 2006). In this paper, a local version of Moran's I statistics (LISA) was used.

Global and local Moran's I statistics were determined in ArcGIS based on Spatial Statistics Tools.

3 Research area

The preliminary research permitted the determination and presentation of the spatial distribution of seven main classes of land cover (Figure 1), as well as calculation of their share in the total area of Poland (Table 2).

Table 2: Share of land-cover classes as a percentage of Poland's surface area.

Legend	Land-cover class	Share (%)
1	Forest and semi-natural areas	33.0
2	Wetlands and water areas	2.1
3	Permanent grasslands	9.0
4	Permanent crops	0.6
5	Other agricultural areas	49.2
6	Other areas	0.5
7	Built-up areas	5.6

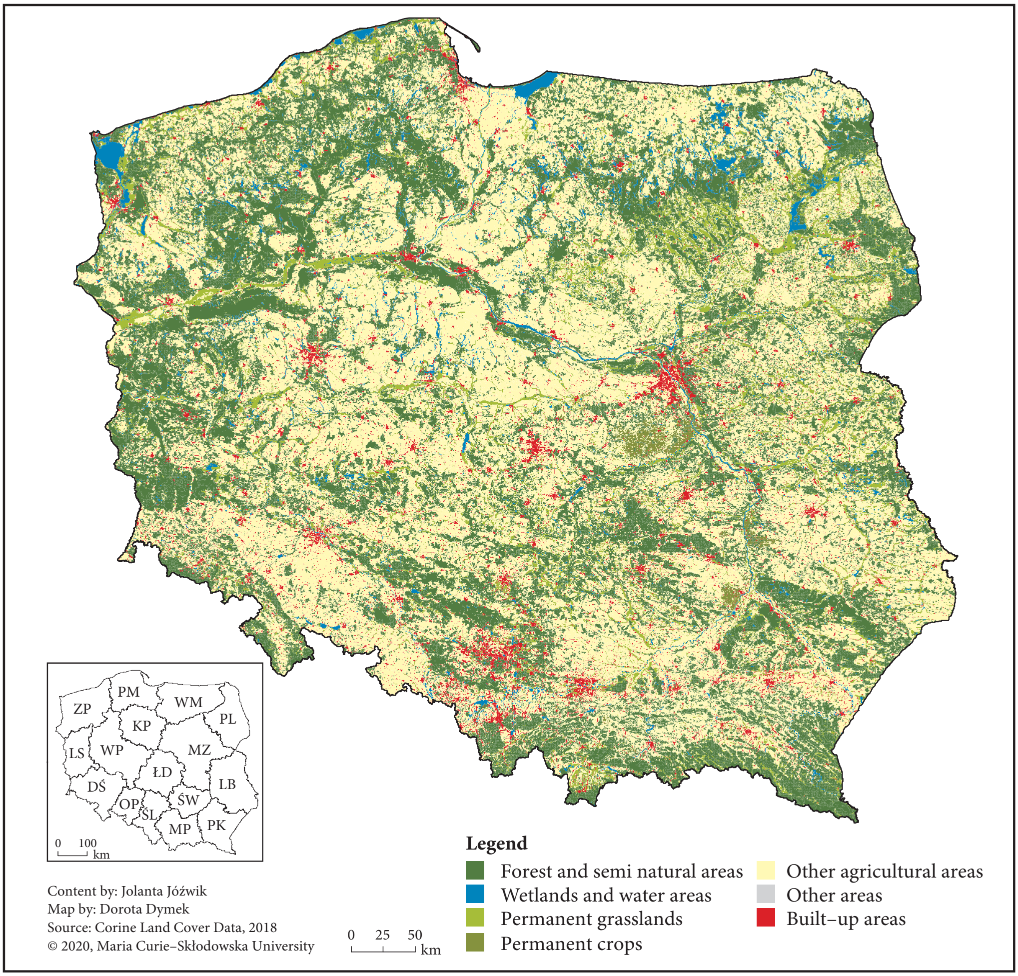

Figure 1: Spatial distribution of the land-cover classes identified. DŚ – Lower Silesia, KP – Kuyavia-Pomerania, LB – Lublin, LS – Lubusz, ŁD – Łódź, MP – Lesser Poland, MZ – Masovia, OP – Opole, PK – Subcarpathia, PL – Podlasie, PM – Pomerania, ŚL – Silesia, ŚW – Holy Cross, WM – Warmia-Masuria, WP – Greater Poland, ZP – West Pomerania.

Over 80% of the country's area is covered by two of the seven classes: other agricultural areas and forest and semi-natural areas; almost half of the country is covered by the former. The highest concentration of these areas occurs in a belt stretching from the north through the central part of the country towards the southwest. Other types of land cover form mosaic systems. The second most dominant class is forest and semi-natural areas, which occupy more than 30% of the area analyzed. They occur in a plane system, particularly in the northwestern and southern part of the country, and in a mosaic system in variable proportions over the remaining area. The remaining classes of land cover occupy a much smaller area, and together account for less than 20% of the country's terrain. Permanent grasslands, primarily located along river valleys and in northeastern Poland, dominate among these classes. a small percentage of the country's area is occupied by wetlands and water areas, as well as built-up (developed) areas. The first two are mainly located in the north of the country. Built-up areas correspond to the settlement network of the country. Larger concentrations of built-up areas occur in administrative capitals and larger cities. Permanent crops occupy the lowest percentage of the area analyzed. They are concentrated in three main basins located in central and eastern Poland, where fruit crops are grown.

4 Results

A detailed analysis of the land-cover classes identified was used to estimate the degree of ecological stability in municipalities. Further in the study, the percentage of areas occupied by individual groups in regional terms and their spatial distribution were analyzed (Figures 2 and 3).

Group a includes heavily urbanized municipalities. The landscape of these areas is not stable or consistent. The municipalities are dispersed, occupying a relatively small percentage of the country's area (4.7%). They only merge into small clusters in several places in Poland.

More than one-third of the country's area (35.7%) is occupied by areas of low ecological stability (group B), forming relatively extensive patches scattered throughout Poland.

Group C occupies the largest area in the country (37.9%). Municipalities belonging to this type form relatively large clusters cutting across areas that primarily belong to group B. In total, groups B and C occupy nearly three-quarters of the area of Poland. These groups also dominate in almost all provinces.

Areas of high ecological stability (group D) cover almost one-fifth of the country's area (18.6%). They are most highly concentrated in northern and western Poland. Small concentrations are also found in the southern and southeastern parts of the country.

Group E occupies the smallest area (only 3.1% of Poland's total area). This type emerges in ecologically stable areas with significant natural functions and little transformation by human activity. Municipalities included in group E are characterized by a high degree of spatial dispersion. They only form a band-shaped cluster along the southeastern border of the country. In the central part of Poland there are hardly any such areas.

The Lubusz Province (LS) compares most favorably to the other provinces. No municipalities classified as group a were recorded there, and more than half of the province's area (70.4%) belongs to groups D and E. The most unfavorable situation occurs in the Łódź (ŁD) and Kuyavia-Pomerania (KP) Provinces. More than half of their area is occupied by groups a and B.

Visual evaluation of the obtained results suggests the occurrence of spatial autocorrelation. To confirm this assumption, global Moran's I statistics were used. The calculations employed the spatial weighting matrix resulting from linear standardization of the neighborhood matrix, where a common boundary expressed by linear or point contact was used as a criterion of neighborhood. The statistic value obtained is 0.542 (significantly different from 0). The positive sign means that the analyzed case shows a tendency to concentrate units with similar CEI value in the neighborhood. Moreover, given the z-score of more than 2.58 and p-value < 0.001, the likelihood that this clustered pattern could be the result of random chance is less than 1%. The high values of global Moran's I statistics are confirmed by the image obtained from the Local Indicators of Spatial Association (LISA) analysis. This analysis allowed to confirm the assumption of the occurrence of cluster systems in the spatial distribution structure of the CEI (Figure 4).

In the second variant, the percentage of areas corresponding to particular classes of ecological stability changed quite significantly (Figures 5 and 6). Among all the distinguished classes, areas included in group a constitute by far the largest surface area of the country (41.0%). a similar dynamic is observed at the subnational (provincial) level. Almost all of the provinces are dominated by this class, and in several cases these areas occupy up to half of their area. The highest concentration of these areas occurs in central and western Poland, and in a belt stretching from the southwest to the southeast. Areas belonging to group B occupy a relatively small area of Poland (12.9%). They are characterized by a mosaic system and significant dispersion throughout the country. They are primarily located in the vicinity of areas classified under group A. Greater concentrations of these (B group) areas occur in the Masovia (MZ), Łódź (ŁD), Holy Cross (ŚW), Lublin (LB), and Podlasie (PL) Provinces. Group C shows similar dynamics. These areas occupy the smallest area in the country (10.2%), and are characterized by significant, but uniform dispersion. Areas included in group C do not merge into larger clusters. The situation is slightly different for areas with high ecological stability (group D). These areas are considerably scattered throughout the country, and occupy a similar percentage of the area as groups B and C (11.1%). They merge and form several larger clusters, particularly in the northern part of the country. The differences in the share of groups B, C, and D across all provinces are not significant, and remain at a similar level. The second largest group in

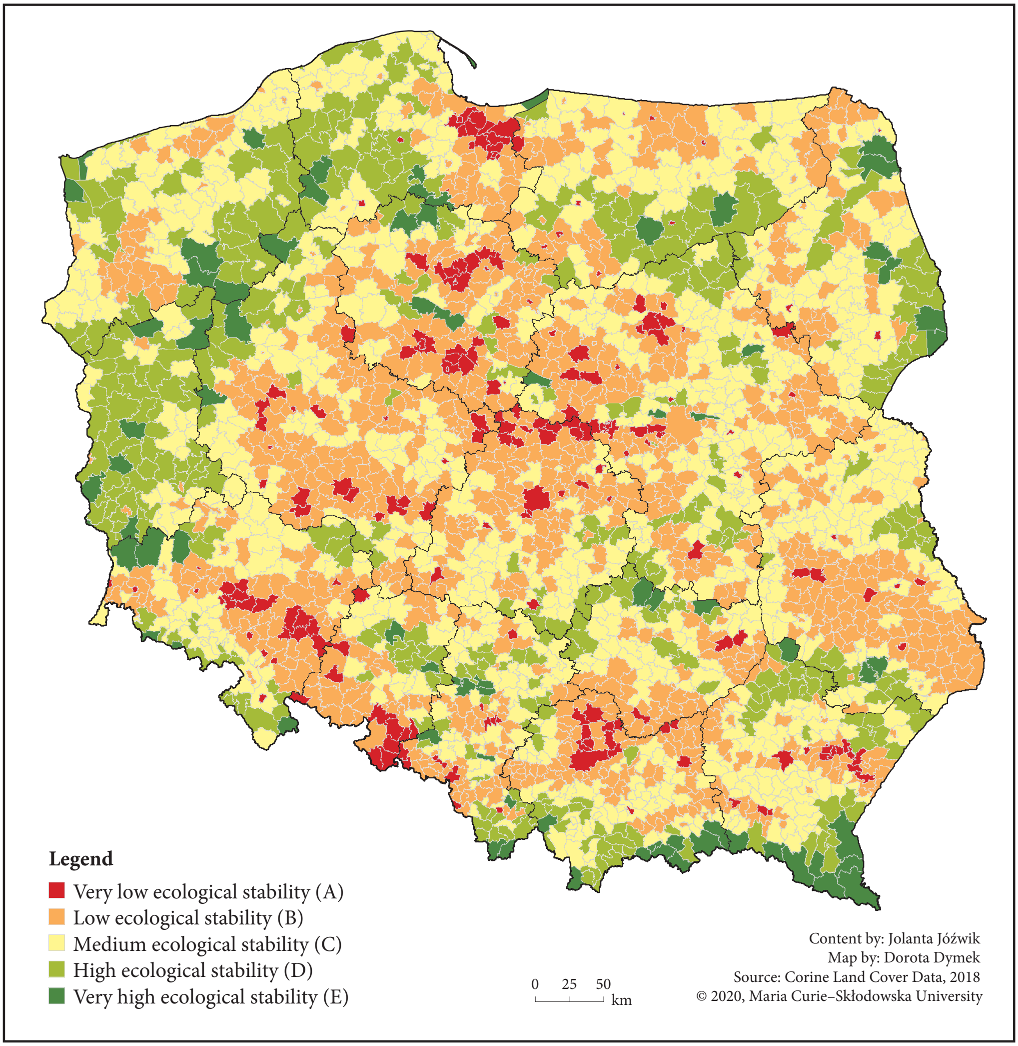

Figure 2: Spatial distribution of Poland's ecological stability classes based on the CEI value (BUA: municipalities).

terms of surface area is group E (24.9%). The spatial distribution of this group is fairly diversified. Areas of this type occur in both mosaic and plane systems. The highest concentration of these areas is located in the northern, western, and southern parts of Poland.

Like in the first variant, the most favorable situation in terms of ecological stability occurred in the Lubusz Province (LS), where groups D and E cover over 50.0% of the area. The worst situation occurred in the Łódź (ŁD) and Kuyavia-Pomerania (KP) Provinces, where groups a and B cover more than 60.0%. In this variant, the latter also included the Opole (OP) and Greater Poland (WP) Provinces.

Like in the case of municipalities, the global Moran's I statistics indicated the occurrence of spatial autocorrelation. The statistics value obtained was 0.716, suggesting a tendency to group units with similar CEI values. Given the z-score of more than 2.58 and p-value < 0.001, also in this case the likelihood that this clustered pattern could be the result of random chance is less than 1%. LISA analysis confirmed the occurrence of clusters in the area analyzed (Figure 7).

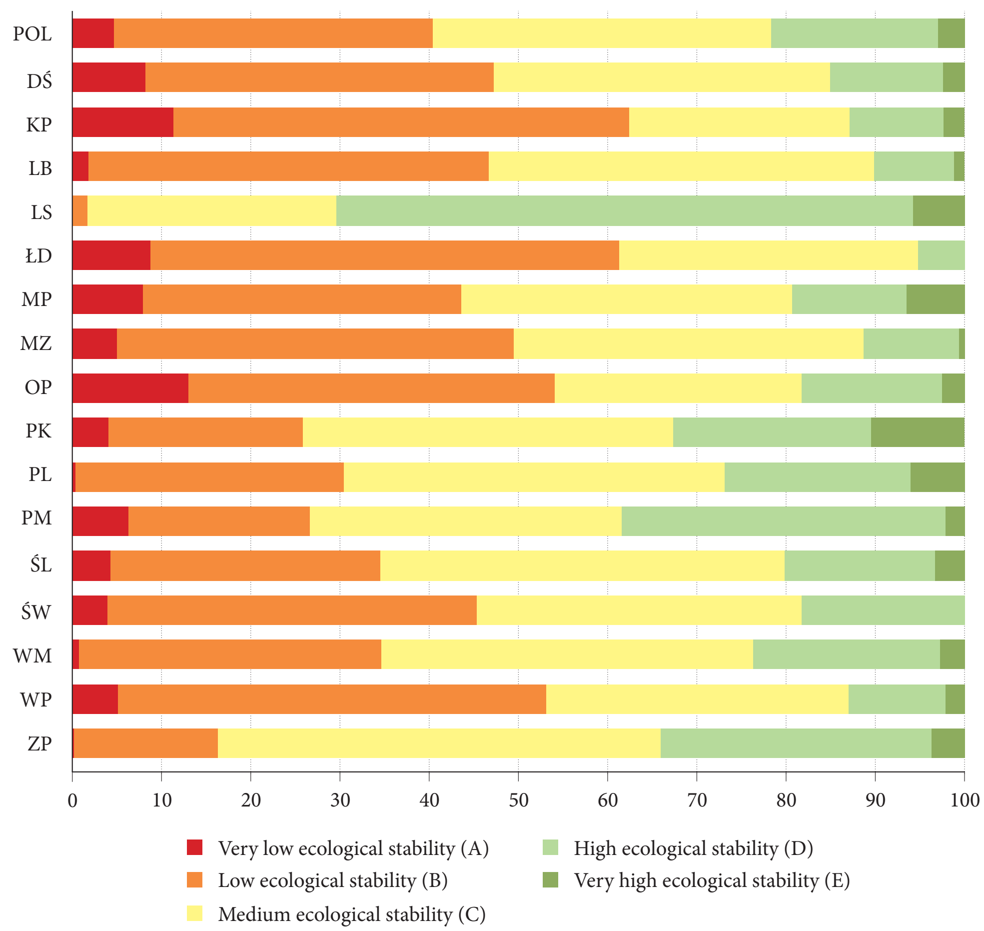

Figure 3: Share (%) of ecological stability classes at the national and provincial level (BUA: municipalities). POL – Poland, DŚ – Lower Silesia, KP – Kuyavia-Pomerania, LB – Lublin, LS – Lubusz, ŁD – Łódź, MP – Lesser Poland, MZ – Masovia, OP – Opole, PK – Subcarpathia, PL – Podlasie, PM – Pomerania, ŚL – Silesia, ŚW – Holy Cross, WM – Warmia-Masuria, WP – Greater Poland, ZP – West Pomerania.

5 Discussion

This study estimates the degree of ecological stability at the level of administrative units in Poland. The assessment was performed in two variants. The units originally analyzed were municipalities (Pol. *gminy*). The verification of the results obtained involved extending the study. a square with sides of 1 km was used as the basic unit of assessment. The spatial analyses conducted also permitted the spatial dependence of the phenomenon to be identified and spatially illustrated.

This research is an important contribution to Polish research on ecological stability. Owing to the use of the CLC 2018 unified database, the method is characterized by a relatively high level of detail and high degree of objectivity. The basic unit of assessment applied (an artificial geometric division: a square with sides of 1 km) permitted comparison of units with each other, which until now was not possible due to different types of spatial units used by other authors. Moreover, the analysis was carried out for the entire

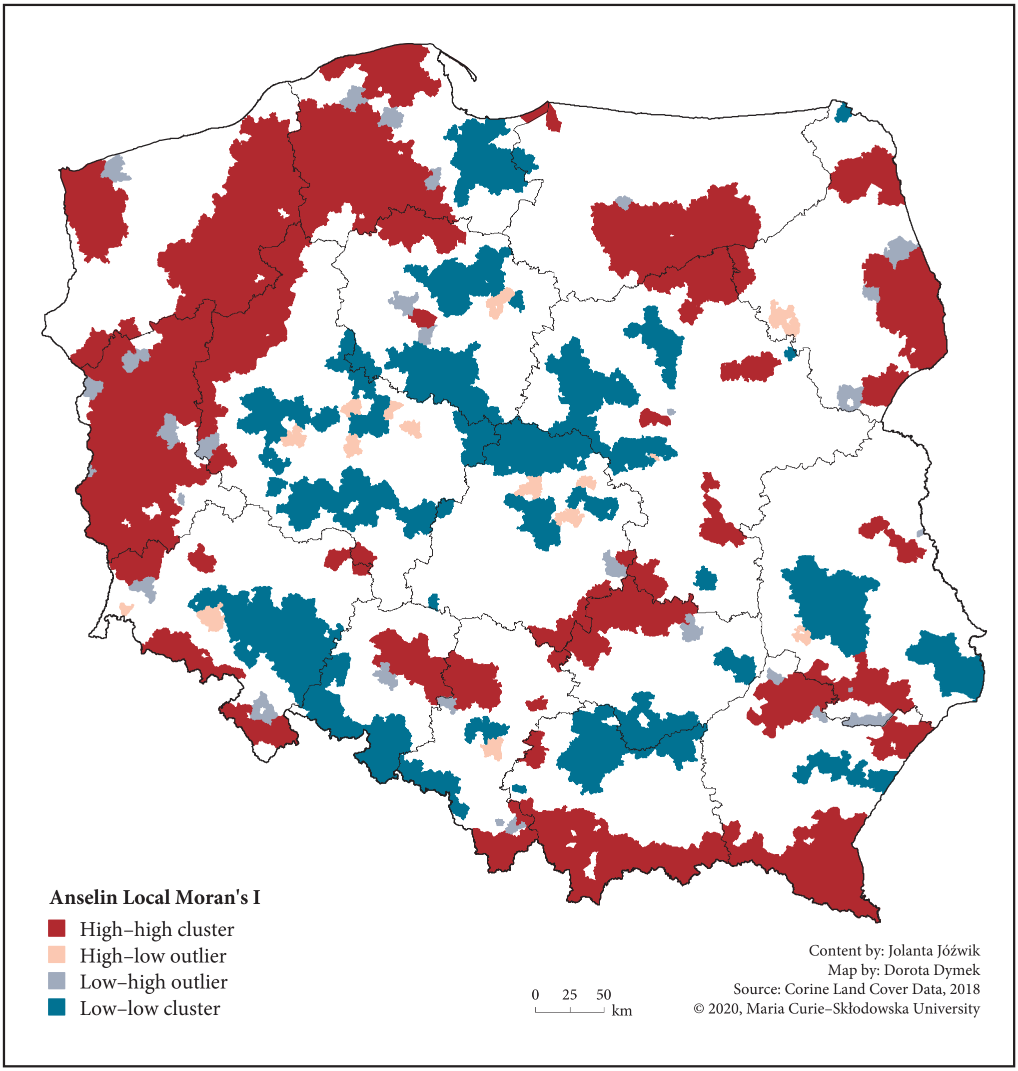

Figure 4: Distribution of cluster and outlier analysis (Anselin Local Moran's I) for CEI in Poland (BUA: municipalities).

territory of Poland, allowing for some conclusions regarding Poland's ecological stability to be drawn. The added value of the study is the extension of the statistical analysis to include a spatial analysis which, by demonstrating the spatial dependence of the ecological stability of the landscape, confirmed the occurrence of spatial units with similar values in close neighborhoods (clusters).

Adopting Poland's principal administrative units (municipalities) as BUAs revealed a clear dominance of areas concentrated around low and medium ecological stability (groups B and C). Using the second variant (artificial geometric divisions) showed the predominance of groups with extreme CEI values (group a and group E) which constituted a small percentage of the total in the first approach. Regardless of the variant applied, the most favorable situation in terms of ecological stability was observed in the following provinces: Lubusz (LS), Subcarpathia (PK), and West Pomerania (ZP). Moreover, in the case of the Subcarpathia Province (PK), the result is similar to the results of research for this area presented in 2016 by Salata et al., where a different database was used, one that is slightly more accurate than that used in

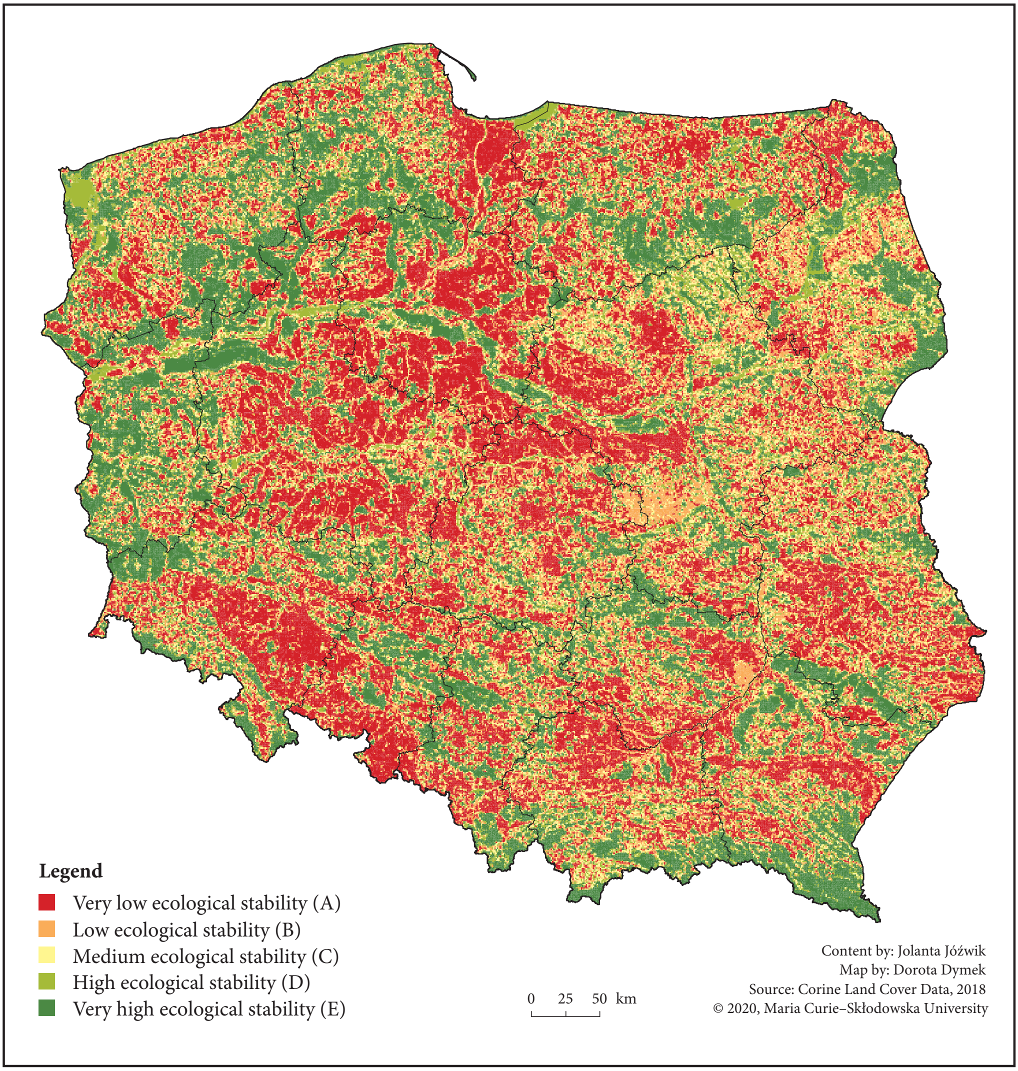

Figure 5: Spatial distribution of Poland's ecological stability classes based on CEI value (BUA: a square with sides of 1 km).

this work. This proves that the method described here can be a useful tool for comparisons between other European Union countries based on a database made according to uniform principles: the CLC database.

The heterogeneity of the results derives from the type and size of the basic units of assessment that were used. As expected, the larger the BUA, the less accurate the obtained results. Both variants have their advantages and disadvantages. The first approach reflects the general character of the municipalities fairly well, and provides a relatively easy and clear message for non-specialists, especially decision-makers at various administrative levels. The second variant is much more precise, and reflects the actual state of the analyzed areas more accurately, while the equal area of each BUA facilitates comparison of results (Balon and Krąż 2013). This approach may facilitate the identification of sensitive areas where fluctuations in the level of ecological stability are likely to occur. It should be emphasized, however, that according to the logic of ecological fallacy, it is not appropriate to transfer conclusions for the examined elements to every single unit of area that makes up that element.

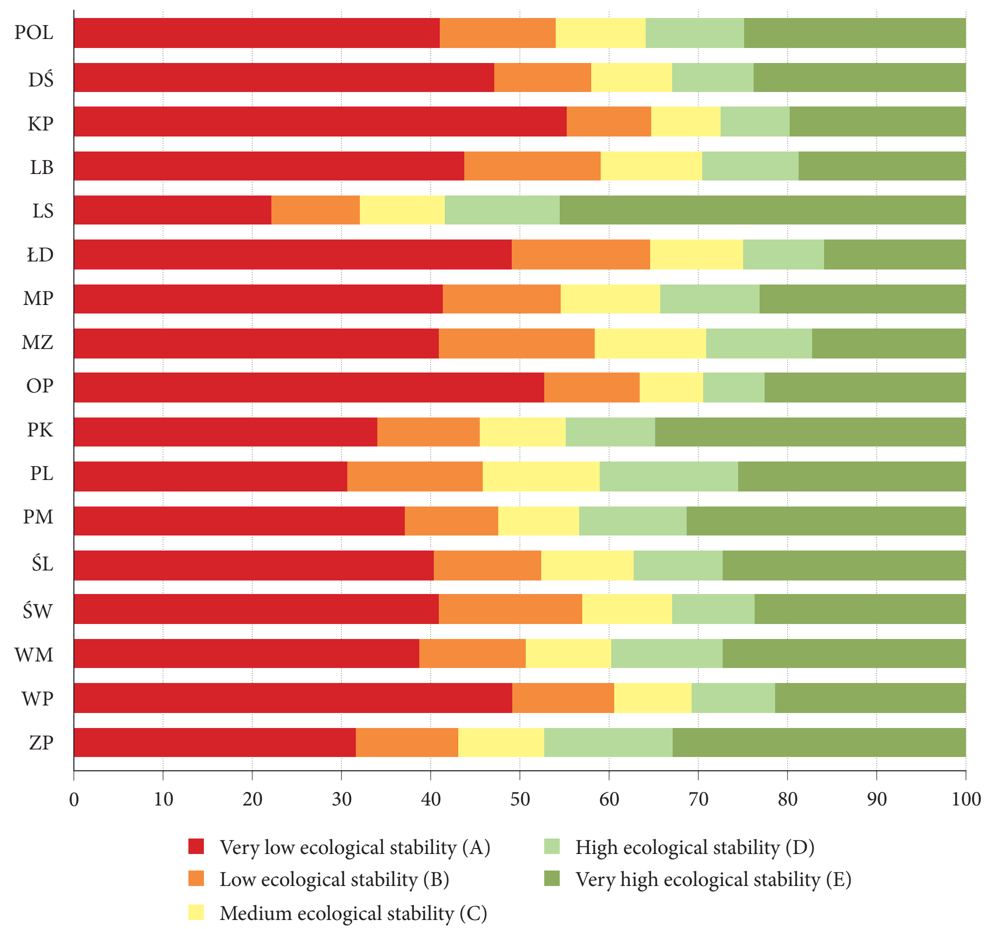

Figure 6: Share (%) of ecological stability classes at the national and provincial level (BUA: a square with sides of 1 km). POL – Poland, DŚ – Lower Silesia, KP – Kuyavia-Pomerania, LB – Lublin, LS – Lubusz, ŁD – Łódź, MP – Lesser Poland, MZ – Masovia, OP – Opole, PK – Subcarpathia, PL – Podlasie, PM – Pomerania, ŚL – Silesia, ŚW – Holy Cross, WM – Warmia-Masuria, WP – Greater Poland, ZP – West Pomerania.

The cartographic presentation of the studied phenomenon made it possible to distinguish two main systems of spatial distribution of ecological stability values, namely the plane system and the mosaic system. From the ecological point of view, the plane system is more advantageous to the extent that it is configured as a compact complex of areas that are easier to manage. The mosaic system is unfavorable, due to its significant dispersion and high internal heterogeneity of individual areas. These systems are characterized by relatively high volatility; that is, the susceptibility to transitioning rapidly to extreme states (Balon 2004; Gałaś and Gałaś 2009). Therefore, areas with mosaic systems should be given special attention to avoid further deterioration of their ecological stability.

In the case of environmentally valuable areas, it is not desirable to have low or very low values of the ecological stability index in the neighborhood. It may lead to the weakening of their potential. High fragmentation and dispersion of areas included in group E make it significantly more difficult – and, in extreme cases, impossible – to ensure that they remain undegraded. It is very difficult to take effective protective

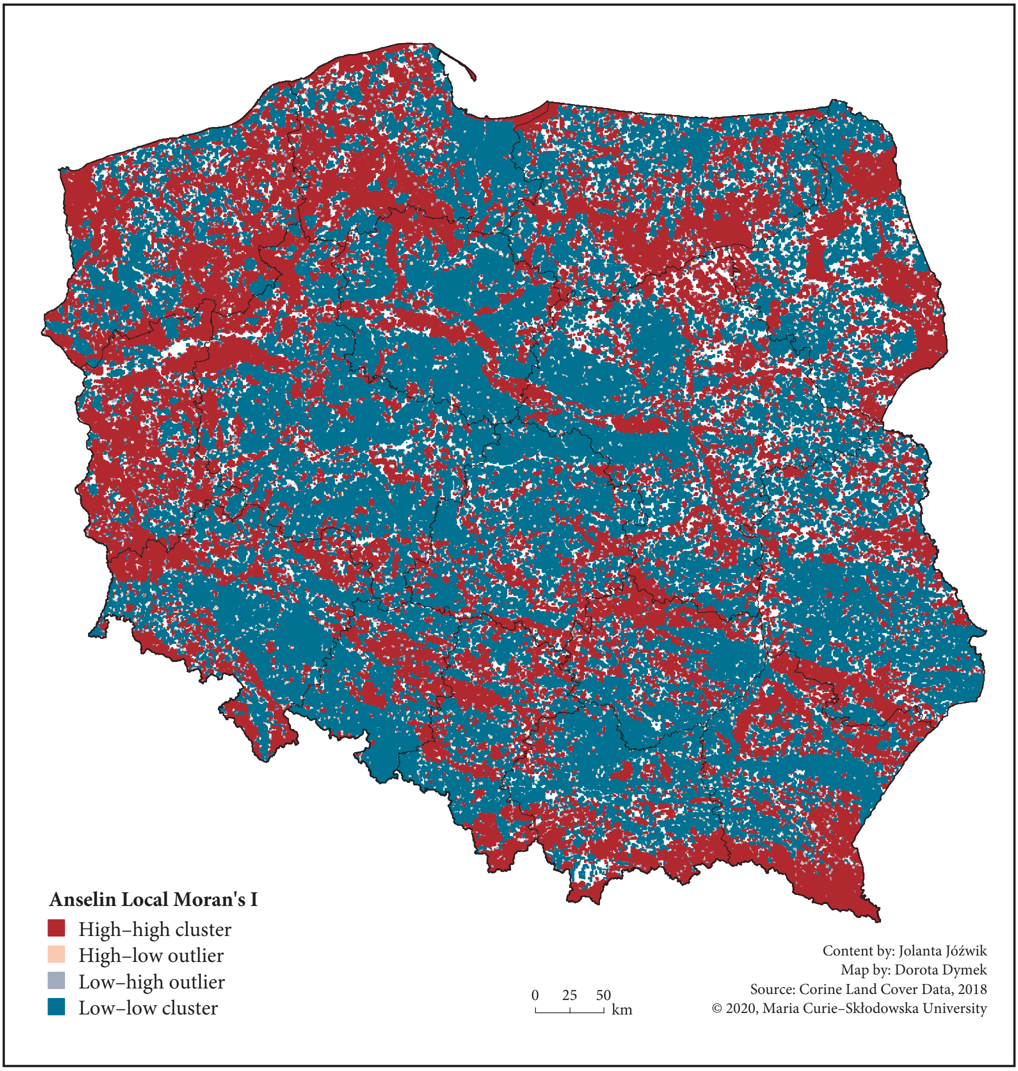

Figure 7: Distribution of cluster and outlier analysis (Anselin Local Moran's I) for CEI in Poland (BUA: a square with sides of 1 km).

measures in such areas. Moreover, the risk of irrational economic management in these areas is high, which in turn may contribute to harmful changes in the way they are administered, and in extreme cases to a complete loss of ecological potential. Such areas require both specialized knowledge and well-thought-out actions. On the other hand, mosaic systems can contribute to a sustainable flow of ecosystem services, enrich the landscape structure, and enhance the landscape's aesthetic values (Waldhardt et al. 2004), prevent soil erosion (Boardman and Poesen 2006), and significantly reduce spatial tensions and conflicts between stakeholders.

Research on the degree of ecological stability of a given area can be very useful for the implementation of beneficial land cover or changes in land use. Area analyses of this type can be applied in practice both at the initial and final stages of spatial development planning (as an important element of environmental management), in addition to being helpful in the preparation of landscape audits. They may be used to identify resources and evaluate their potential for further use.

6 Conclusions

The objective of this study was to compare the spatial diversity of administrative units' ecological stability, and to calculate the spatial autocorrelation of the phenomenon studied in order to study spatial dependencies. An additional goal was to verify the results obtained by comparing them with an artificial geometric division; that is, squares with sides of 1 km. The methods applied were sufficient for achieving the research objective. The results' degree of detail mainly depends on the spatial unit used. Analyses of this type based on a geographical information system can be easily modified and adjusted depending on the purpose and area of analysis. Moreover, the applied method confirms that the CLC database can be successfully used to determine a site's degree of ecological stability. It also permits continuous monitoring of changes in land cover or land-use structure, and can be a useful tool that supports sustainable development policies.

The research showed that the use of different types of spatial units – administrative units (municipalities), and artificial geometric divisions (squares with sides of 1 km) – significantly affects the results: the larger the basic unit of assessment, the less accurate the results obtained. In the first variant (BUA: municipalities), areas with low and average ecological stability were clearly dominant. It can be concluded that the ecological stability of Poland was close to the average level. The second approach (BUA: a square with sides of 1 km) yielded dominance of extreme areas in terms of ecological stability. Regardless of the adopted variant, the most advantageous situation regarding ecological stability was determined in the Lubusz Province, and the most unfavorable in the Łódź and Kuyavia-Pomerania Provinces. In both cases, the results of the global Moran's I and LISA analysis confirmed and illustrated the occurrence of spatial dependencies of the phenomenon studied.

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